CAREER: Structure and Dynamics of Disordered and Out-of-Equilibrium Systems

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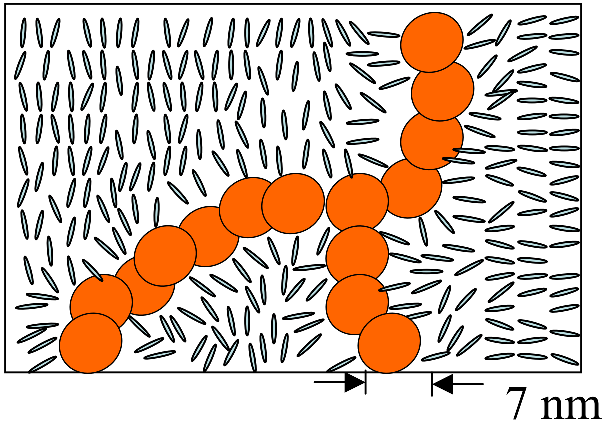
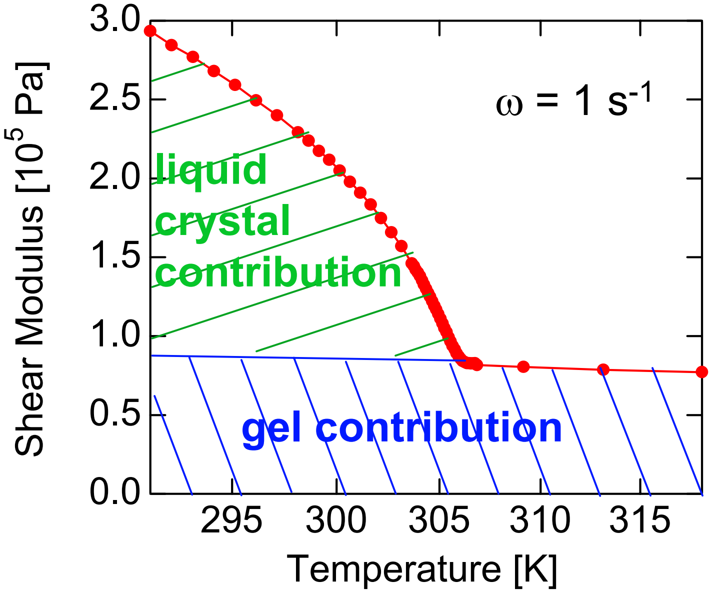
Research Highlight:

Synergistic Mechanical Strength of Liquid Crystal -- Colloidal Gel Nanocomposites.

In liquid crystals, the molecules form arrangements intermediate between disordered liquids and fully order crystals. For example, in smectic liquid crystals, the molecules arrange in layers. We have studied how the mechanical strength of a smectic liquid crystal is influenced by the presence of nanometer-scale particles that are linked into a network, as shown in the cartoon in the upper right. We find that the network disrupts the layering in a manner that enhances dramatically the mechanical rigidity of the fluid. For example, in the data shown on the right, the low-temperature liquid crystal contribution to the shear modulus, a measure of a material's resistance to changes in shape, exceeds 2 x 10^5 Pascals, which is more than 1000 times greater than the values measured in the absence of the particles. This observation should provide new insight into the microscopic mechanisms responsible for giving materials their strength and could lead to new applications for liquid crystals, important materials for optical devices such as displays.





The strength of a solid is typically determined not by intrinsic properties of the ideal substance but instead by its imperfections. Indeed, the scientific basis for the practice of alloying metals is that impurities modify the imperfections in a crystalline solid, thus altering the metal's strength. Liquid crystals are fluids with properties intermediate between liquids and solids. An important example is a smectic liquid crystal in which the molecules arrange in layers. While imperfections in the layering surely play an important role in a smectic's strength, controlling them is a challenge since, unlike for crystals, impurities cannot be frozen into the smectic fluid. We are studying smectic liquid crystals in which we suspend a dilute quantity (around 1% by volume) of nanometer-sized glass spheres that stick together to form a tenuous network, or gel. The gel disrupts the layering, causing imperfections. We characterize the strength of the liquid crystal containing the gel by measuring the shear modulus, which is found by placing the fluid between parallel plates and measuring the force required to slide one plate while keeping the other stationary. At high temperatures, no layers are present in the fluid and the rigidity of the gel dominates. At temperatures below 305 K, the degree of layering increases, and the modulus of the liquid crystal becomes an increasing contribution to the overall strength. The value of the smectic shear modulus grows to more than 1000 times the size of the modulus in the absence of the gel. Thus, imperfections in the layering caused by the gel, as well as the effect the gel has on the imperfections' motion, dramatically alter the strength of the smectic liquid crystal.

Education and Outreach Highlight:

“JHU Physics on the Road”

We have founded an outreach group, comprised largely of undergraduate and graduate students, in the Johns Hopkins Dept. of Physics and Astronomy. A major activity of the group is conducting hands-on physics demonstrations at local public middle schools designed to spark students’ interest in science.

Eighth-graders experience consequences of the laws of rotational dynamics during a visit by the JHU group to Roland Park Middle School in Baltimore, Maryland, April 2004.